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Bamboo as a complementary crop to address climate change and livelihoods – Insights from India

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ABSTRACT

The government of India has recently amended forest act 1927, whereby Bamboo grown in non-forest areas has been removed from the purview of restrictions on its felling and interstate transportation. The new regulation is aimed to increase the commercialization of Bamboo and help in fulfilling the government's commitment to double farmers' income by 2022. It will boost the interest of farmers and entrepreneurs in cultivation, treatment, and processing of Bamboo, which will not only generate new income avenues but also result in the increased green cover of the country. Bamboo has the potential to generate carbon credits due to high carbon sequestration rates, which can be traded internationally. Farmers can use Bamboo farming in sub-optimal land to generate additional income and improve the fertility of the land. This study is about the 'twofold potential' of Bamboo in improving financial conditions of farmers by utilization of cultivable wasteland and helping in climate change mitigation by avoided deforestation, afforestation, and carbon sequestration. India has approximately 146 million hectares of degraded land. Farmers can earn upto 800 USD per hectare annually by selling raw bamboo from their degraded land. Bamboo cultivation can generate around 10 CERs per hectare annually, which can be traded as carbon credits. Additionally, under-employed farmers can work as skilled workers in bamboo handicraft industry and can earn upto 2700 USD annually at current exchange rates, which is significantly higher than the present average income (1750 USD/annum) of farmers.

1. Introduction

Global warming is one of the serious problems that the world is facing at present (Moreno and Perdomo, 2018). The rising CO_2 level in the atmosphere is the prime contributor to global warming. With respect to chemical substances, the earth is a closed system, which means that no substance is added to or removed from the earth and its environment by an external source. Substances either change their chemical forms or get recycled between earth and its atmosphere. The escalating level of CO_2 in the atmosphere is the outcome of the burning of fossil fuels, which were buried under the earth for millions of years. The carbon stored in those fossil fuels is converted into CO_2 after burning and contributes to global warming through the greenhouse effect.

At present, India is the third leading emitter of CO_2 next to China and USA (Global carbon atlas, 2018). This scenario will worsen further in the near future. The share of India's global energy use will rise to 11% by 2040 from 6% in 2015. This projected increase in energy consumption is equivalent to the total energy consumption of today's European Union(World Energy Outlook, 2017; India Energy outlook-, 2015). Efforts at International levels are being initiated to address the problem of global warming and climate change. The United Nations Framework Convention on Climate Change (UNFCC) passed a landmark resolution in 2015 at Paris (COP 21). The resolution of the Paris agreement is to limit the average temperature of earth from rising below 2 °C from the level of the pre-industrialisation period (Paris agreement, 2015). To achieve this ambitious target multifaceted steps are being taken by different countries and organization.

Carbon sequestration has the potential to offset fossil fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions (Lal, 2004). It is a method of capturing CO_2 from the atmosphere or from a point source like fossil fuel based power plant and storing it for a very long duration under the earth surface. CO_2 Sequestration from the atmosphere through plants is a very effective, natural and inexpensive process (Mathew et al., 2017).

Bamboo is the fastest growing plant and matures early as compared

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Nomenclature

A/R	Afforestation and Reforestation
CBTC	Cane and Bamboo Technology Centre, Guwahati
CCM	Climate Change Mitigation
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
COP	Conference Of Parties
DBH	Diameter at the level of Breast Height
DCH	Development Commissioner (Handicrafts)
DNA	Designated National Authorities
FSI	Forest Survey of India
GDP	Gross Domestic Product
GHG	Green House Gases
HBP	Harvested Bamboo products
IET	International Emission Trade
INBAR	International Network for Bamboo and Rattan
IPCC	International Panel on Climate Change
JI	Joint Implementation
NBM	National Bamboo Mission
NER	North East Region
REDD	Reduce Emissions from Deforestation and Degradation
RSR	Root to Shoot Ratio
UNFCC	United Nations Framework Convention on Climate Change
VCM	Voluntary Carbon Markets

to other plants (Liese and Kohl, 2015). It has great potential for capturing carbon and storing it. The potential of CO_2 sequestration in bamboo depends on growth rate and life cycle and hence, varies from species to species. Bamboo starts producing yield in 3–4 years after the plantation and thereafter the same amount of yield is produced every year, (Hunter, 2003). The stored carbon can easily be maintained for a long time in harvested bamboo products or in soil through conversion into biochar. India has a rich diversity of bamboo resources with136 species out of more than 1000 species found worldwide (Nath et al., 2009; Bystriakova et al., 2003). In India bamboo is grown in a wide range of habitats in around 10 million hectares of land that includes forest and private plantations ranging from sea level to over 3500 m (Nath et al., 2009).

International Panel on Climate Change (IPCC) has recommended many corrective steps to control increasing CO_2 emissions such as reforestation and the conversion of the agricultural land into agro silvicultural systems (IPCC Climate change, 2001). Bamboos form the essential part of agro-silvicultural systems and play an important role in the CO_2 balance of the earth's ecosystem through CO_2 sequestration from the atmosphere (Nath et al., 2009). Bamboo reduces soil erosion rate and requires a lesser amount of fertilizers and chemicals. Bamboo can complement traditional crops and be used as an alternative to the wood (Ly et al., 2012).

Bamboo is also able to grow in poor quality soil. It can be a significant factor for the country like India with a large degraded land area. Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. In other words, it is the return of a damaged ecological system to a stable, healthy, and sustainable state (Mishra et al., 2014). Under an INBAR project Bamboo species were used to rehabilitate soil, which was degraded due to brickfield mining near Allahabad (India). Bamboo was grown on the residual soil and the quality of soil improved significantly in a few years (Yiping et al., 2010). In addition to helping the ecosystem, bamboo is used in the construction of traditional houses and as fuel wood in villages. It also provides protection to houses from wind (Nath et al., 2009).

Carbon farming has received a lot of attention after the Kyoto protocol. INBAR has been making constant efforts for the inclusion of bamboo in carbon trade mechanisms like the Clean Development Mechanism (CDM) and Voluntary Carbon Markets (VCM). However, new methodologies to calculate carbon credits from bamboo cultivation are required to be developed (Yiping et al., 2010). The studies on the potential of carbon sequestration in different species of bamboo have contrasting conclusions. However, all studies unanimously conclude that 'fast growth rate' and 'short time for maturity' give bamboo an edge over other competing plant species. India is one of the most vulnerable countries with respect to global warming (Ayers and Huq, 2007). India is also struggling economically in pursuit of all-round development of its huge population under the poverty line. The country has a target of reducing its emission intensity of GDP by 33–35% from 2005 levels before 2030 (UNFCC, 2017). Bamboo is uniquely placed to help the environment by mitigating CO_2 levels and generate financial gains to farmers in multiple ways (through the trade of carbon credits, the sale of bamboo products and growth in agricultural production with the usage of biochar).

Bamboo products have significant international demands with USA and EU accounting for 80% of total bamboo imports at present, most of it originating from China (Hunter, 2003). Bamboo can effectively provide financial gains and adaptation to climate change at the village levels. It also helps in climate change mitigation at the global level because of its multiple uses and suitability to diverse conditions. Bamboo helps in erosion control, watershed protection and can be used as a timber substitute in the forest ecosystem. Bamboo cultivation requires little fertilizer and pesticides, which makes it an economically favorable crop (INBAR, 2006). Bamboo species can be classified into three groups sympodial, monopodial and amphipodial. Each class has many different species, which are suitable for varied applications such as manufacturing, agrarian, decorative and environmental conservation etc. (Maoyi and Banik, 1996).

The present study discusses the scope of climate change mitigation and financial gains through bamboo cultivation. Carbon credits (from avoided deforestation, afforestation, and carbon sequestration) and potential applications of bamboo are also discussed in the Indian scenario. It is recommended that farmers can use bamboo farming in suboptimal land to generate additional income and improve the fertility of the land.

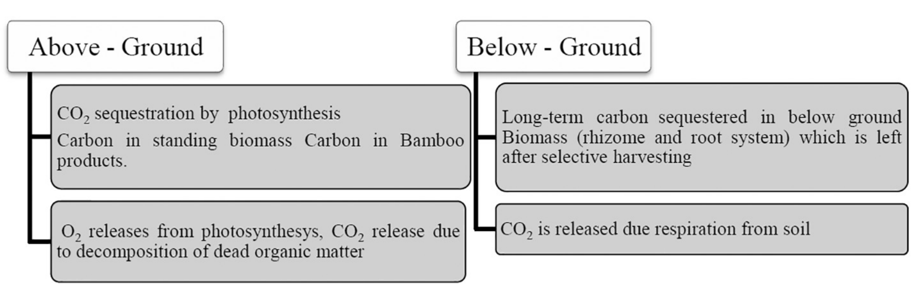

Fig. 1. Bamboo carbon cycle.

2. Carbon sequestration through bamboo cultivation

Bamboos are useful in carbon sequestration through all main types of forest-based climate change activities namely (i) Afforestation and re-forestation (ii) Forest management (iii) Avoided deforestation. The carbon cycle includes the above and underground activities which can be shown in Fig. 1 (YannickKuehl et al., 2011).

The direct and indirect methods are used for biomass estimation in different parts of bamboo plants. The direct method, also known as the destructive method is time-consuming and comparatively more expensive. The indirect method is a non-destructive method and involves indirect measurement of the biomass of a plant. In this method, an allometric correlation is developed between parameters such as Diameter at the level of Breast Height (DBH) and its full height (H) for biomass estimation (Singnar et al., 2017). The indirect method is preferred since it consumes less time and is less expensive compared to the direct method (Verwijst and Telenius, 1999; St Clair, 1993).

The carbon and biomass stocks depend on the species of bamboo and geographical location. A study was carried out at Barak valley in north-eastern states of India consisting of three species, *B. Cacharensis* (46%), *B. Vulgaris* (28%) and *B. Balcooa* (26%). The total carbon stock in the bamboo plantation was approximately 120.75 t/ha. Carbon storage in the above-ground biomass, litter floor mass and in the soil (up to 30 cm depth) was 61.05 t/ha, 2.40 t/ha and 57.3 t/ha respectively (Nath et al., 2009). Another study was carried out on most popular Japanese bamboo species' *Phyllostachys Pubescens*. The gross production of carbon was estimated 32.81 t/(ha × yr) which consist of 18.11 t/ha in above and 11 t/ha in belowground biomass (Isagi et al., 1997). In Indian dry deciduous forests carbon storage by *d. strictus* plantation was estimated to be 96.35 t/ ha. Out of this below ground was 26% and above ground was 74% (Singh et al., 2006). In Taiwanese Makino Bamboo, annual carbon sequestration rate of 9.89 t/ha was estimated with the assumption that the selective harvesting of 20% clumps was done each year. It was concluded that Makino Bamboo would achieve the carbon storage value of a 33-year-old Japanese cedar in 14.8 years and that of a 29-year-old Taiwanese red cypress in 8.3 years only (Yen et al., 2010). The yearly carbon sequestration rate of Moso Bamboo was found at 8.1 t/(ha × yr) when extensively managed (Tending, cutting bamboo and harvesting bamboo shoots). It was observed to increase upto 12.7 t/(ha × yr) with intensive management (fertilizing annually, tending, harvesting bamboo and bamboo shoots periodically). It is approximately 3.6 times the carbon sequestration rate of Chinese Fir, and 2–4 times that of tropical rainforests and pine plantations (Yiping et al., 2010). Annual carbon sequestration through fast-growing species Schizostachyum pergracile and Bambusa bamboos were found to be 26.96 and 20.5 t/(ha × yr) respectively (Thokchom and Yadav, 2017; Das and Chaturvedi, 2006). Carbon sequestration data in respect of some of the bamboo species has been summarized at Table 1 from the published literature (Nath et al., 2015: Yuen et al., 2017).

It is concluded that carbon storage and sequestration rate of 30–145 t/ha and 1.3–24 t/(ha × yr) respectively, can be achieved from different species of bamboo. The global average carbon storage in forest vegetation is around 86 t/ha (Wei et al., 2007), which can be surpassed easily by the properly managed bamboo plantation. Bamboo is required to be properly managed to achieve maximum sequestration of CO_2. It is pertinent to mention that bamboo management includes periodic harvesting of selected culms. Carbon stored in the harvested culms is also included in the calculations for comparison with other forest-based choices (Yiping et al., 2010).

3. Bamboo in Indian scenario

Bamboo (23 genera and 136 species) occupies 12.8% of total forest area in India. Northeast India is particularly rich in bamboo as more than 50% of species found there (FSI, 2017). In India 156,866 sq. km area is covered under bamboo forests holding an estimated 28,103 million culms equivalent to 188,759 thousand tonnes of bamboo by weight. Madhya Pradesh, Maharashtra, and Arunachal Pradesh states are top three according to the area covered under bamboo forests. In terms of a total number of culms; Arunachal Pradesh, Assam, and Madhya Pradesh are the top three states. Whereas, in terms of weight, Arunachal Pradesh, Karnataka, and Assam states are at the top three positions respectively (FSI, 2017). State-wise data according to the area, no. of culms and weight is given in Table 2. Relative positions of states according to their percentage share in the total volume of bamboo inventory are represented in Fig. 2 (FSI, 2017). By careful

Table 1
Carbon stock and sequestration rate in different species of bamboo.

S. No.	Name of the species	Study site	Culm density (number ha^{-1})	Carbon density (Mg ha^{-1}) Above Ground	Below ground*	Mean annual carbon accumulation rate (Mg ha^{-1} yr^{-1})*	Reference
1.	B. cacharensis	India	5626	16.39	38.3	1.3	Nath et al., 2018
2.	*B. vulgaris*	India	4800	38.42	89.6	2.3	Nath et al., 2018
3.	*B. balcooa*	India	2216	19.64	45.7	1.6	Nath et al., 2018
4.	Moso bamboo (Phyllostachy pubescens)	China	-	34.231	72.131	–	Zhou and Jiang, 2004
5.	Phyllostachys bambusoides	Japan	12,040	52.32	20.8	13	Nath et al., 2015 Yuen et al., 2017
6.	*Phyllostachys makinoi*	Taiwan	21,191	49.81	90.1	9.89	Yen et al., 2010, Yuen et al., 2017
7.	*Bambusa blumeana*	Philippines	7600	71.5	21.5	–	Uchimura, 1978
8.	*Gigantochloa levis*	Philippines	9300	73.4	–	–	Suzuki, 1989
9.	Gigantochloa ater & G.verticilleta	Indonesia	6820	37	26.64	–	Christanty et al., 1996, Yuen et al., 2017
10.	*Phyllostachys pubescens*	Japan	7100	69	37.9	9	Isagi et al., 1997
11.	*Bambusa bambos*	India	4250	144	24.48	24	Shanmughavel and Francis, 1996, Yuen et al., 2017
12.	*Dendrocalamus strictus*	India	27,000	30	25.8	13	Singh and Singh, 1999
13.	Yushania alpina	Ethiopia	8840	55	12.8	–	Embaye et al., 2005
14.	Bambusa bambos	India	8000	121	24.5	6	Kumar et al., 2005
15.	Phyllostachys heterocycla	Taiwan	7100	41	22.5	8	Yen and Lee, 2011
16.	*Bambusa oldhamii*	Mexico	10,101	51.5	24.2	16	Castañeda-Mendoza et al., 2005
17.	Phyllostachys pubescens	China	3968	40	22	7	Zhang et al., 2014
18.	*Guadua angustifolia*	Bolivia	4500	100	15	–	Quiroga et al., 2013

* Calculated using Root to Shoot Ration (RSR) where exact data is not mentioned in literature (Yuen et al., 2017).

Table 2
State wise data of Bamboo in India* (FSI, 2017).

Name of the state	Bamboo bearing area (sq. km)	No. of estimated culms (in million)	Estimated equivalent weight (in thousand tonnes)
Andhra Pradesh	7578	1076	9903
Arunanchal Pradesh	15,125	4048	18,863
Assam	8955	2452	14,912
Bihar	1004	353	1692
Chhattisgarh	11,060	1075	5942
Goa	382	26	148
Gujarat	3544	485	6035
Haryana	21	NA	NA
Himanchal Pradesh	540	321	1156
Jharkhand	4470	666	2520
Karnatak	10,442	1166	16,538
Kerala	3484	834	7220
Madhya Pradesh	18,167	2406	9073
Maharashtra	15,927	1816	15,879
Manipur	10,687	2340	15,469
Meghalaya	5943	1323	11,462
Mizoram	3267	716	6217
Nagaland	6025	1301	11,269
Orissa	12,109	1585	9864
Punjab	44	6	27
Rajasthan	1976	831	3661
Sikkim	553	135	305
Tamil Nadu	4154	777	6470
Telangana	4778	651	5009
Tripura	3617	797	6494
Uttar Pradesh	936	175	641
Uttarakhand	1078	267	963
West Bengal	942	464	948
Dadra & Nagar Haveli	58	11	79
Total	**156,866**	**28,103**	**188,759**

* Inadequate data available in respect of A&N islands, Chandigarh, Delhi, Daman & Diu, Lakshdweep, J&K and Pondichery.

observation of state wise data, it can be concluded that almost all parts of India are rich in bamboo diversity.

The recent change in Indian legislation to promote commercial use of bamboo is applicable to bamboo grown in non-forest areas only (The Indian forest (amendment) act, 2017). Hence, it is important to discuss salient features and advantages of the family owned and managed bamboos in the non-forest areas of India. The bamboo species grown by families in Indian villages are normally thick walled Bambusa species (Nath et al., 2018). Most of the species belonging to Bambusa genus are tall and thick. These species are quite popular for farming in family-owned home gardens in India and Bangladesh (Banik, 2000).

In India, 37 species of Bambusa genus are found, which are grown in diverse locations and climatic conditions (Sharma and Nirmala, 2015). Six Bambusa species are included among 13 total species promoted by National Bamboo Mission (NBM) of India (National Bamboo Mission, 2008). According to their frequent occurrences, three species (B. Cacharensis, *B. Vulgaris* and *B. Balcooa*) represent a large portion of the total growing stock of family-owned Bamboo farms in North-East Indian villages (Nath and Das, 2008). The estimated carbon storage in the above-ground biomass is 54.7 t/ha,128 t/ha, and 65.3 t/ha for B. Cacharensis, *B. Vulgaris*, and *B. Balcooa*, respectively (Nath et al., 2018). These values are higher than bamboo species found in unmanaged forests because of the thick-walled structure of the family owned and managed bamboos, unlike the thin-walled forest bamboo species. Additionally, bamboo management practices like fertilization and selective felling have the potential to improve biomass carbon stock (Yuen et al., 2017). In India, bamboo has traditionally been part of life from the ancient age. The main applications of bamboo in India are shown in Fig. 3 (National Bamboo Mission, 2018).

4. Carbon credits and markets

The concept of carbon credits and its trade originated after the Kyoto protocol (1997). Three mechanisms of carbon credits were

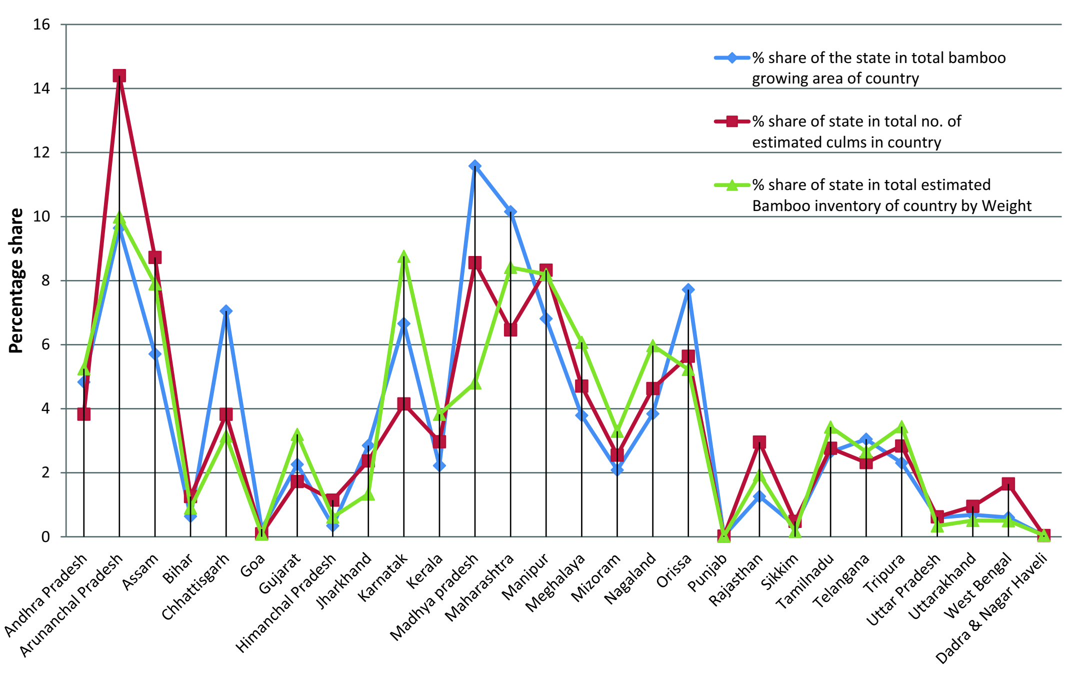

Fig. 2. Share of Indian states in total bamboo stock of the country#. (FSI, 2017).
#Inadequate data available in respect of Haryana, Andman and Nicobar islands, Chandigarh, Delhi, Daman and Diu, Lakshdweep, Jammu and Kashmir, and Pondichery.

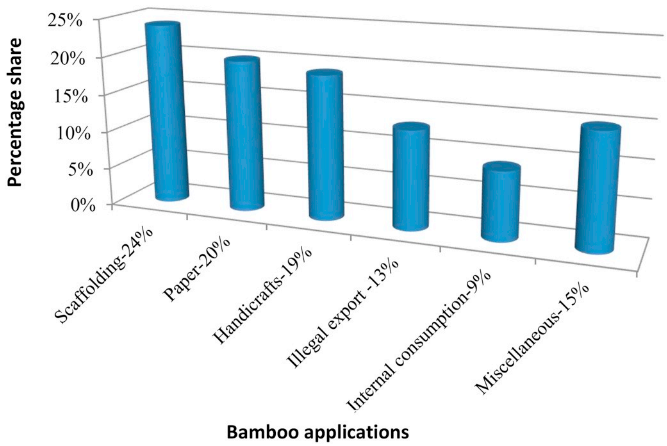

Fig. 3. Percentage share of bamboo applications in India.

proposed under this protocol i.e. Joint Implementation (JI), International Emission Trade (IET) and Clean Development Mechanism (CDM). Carbon farming is one of the projects promoted by CDM as a method of climate change mitigation (Kyoto protocol, 1997). Voluntary Carbon Market (VCM) provides a platform for the trade of carbon credits by companies and individuals who voluntarily wish to offset their emission foot prints (Kamesh and Lokesh Chandra, 2009).

Initially, bamboo was not included among the fast-growing species for plantation under CDM in spite of having fast growth and high biomass productivity since botanically bamboo was considered a grass (Sohel et al., 2015). Later, 39th Executive Board meeting of CDM decided that 'Bamboo' along with 'Palm' could be considered as a tree under afforestation and reforestation (A/R) schemes of CDM. However, the board authorized respective country Designated National Authorities (DNAs) to take a final decision on the inclusion of these species in CDM activities (Lobovikov et al., 2009). There exists a proper chain of events, which has to be followed if a bamboo-based plantation activity is to be approved under the CDM scheme for the award of Certified Emission Reductions (CER) certificate. The sequence of activities is represented in Fig. 4 (CDM, 2018).

A feasibility study regarding bamboo based Carbon Credit generation in Nagaland, India was carried out in coordination with the Cane and Bamboo Technology Centre (CBTC), Guwahati. It reported the scope of generating 190,790 CERs annually in Nagaland alone amounting to 10 CERs per hectare of the bamboo plantation (Kamesh and Lokesh Chandra, 2009). The price of CERs in international exchanges is considerably low at present due to low demand and high supply. The revival of CER prices is expected post implementation of the Paris agreement in 2020.

In many developing countries emissions related to agricultural activities, forestry, and other land usage is the biggest cause of GHGs emission. However, these activities did not get much consideration in the first cycle of the Kyoto protocol, as industry and energy-related emissions were given more importance (Neeff and Francisco, 2009). COP 13 of the UNFCCC at Bali in 2007, a post-Kyoto mechanism to encourage the practices to capture carbon from forestry was proposed. It resulted in a mechanism known as REDD "Reduce Emissions from Deforestation and Degradation". The primary intention of proposing the REDD mechanism was to create financial provisions that could help developing countries in voluntarily reducing their national deforestation rates (Gibbs et al., 2007).

An improved version of the REDD known as REDD+ includes actions that enhance forest health (forest administration, protection, and afforestation) to existing REDD mechanism (REDD+ web platform, 2018). REDD+ has the potential to enhance environmental resources and biodiversity in addition to improving carbon stock levels. The REDD+ mechanism can prove to be a better model for village bamboo growers who could be incentivized for their activities that result in conservation of forests (Yiping et al., 2010). In 2015 at Paris (COP-21),

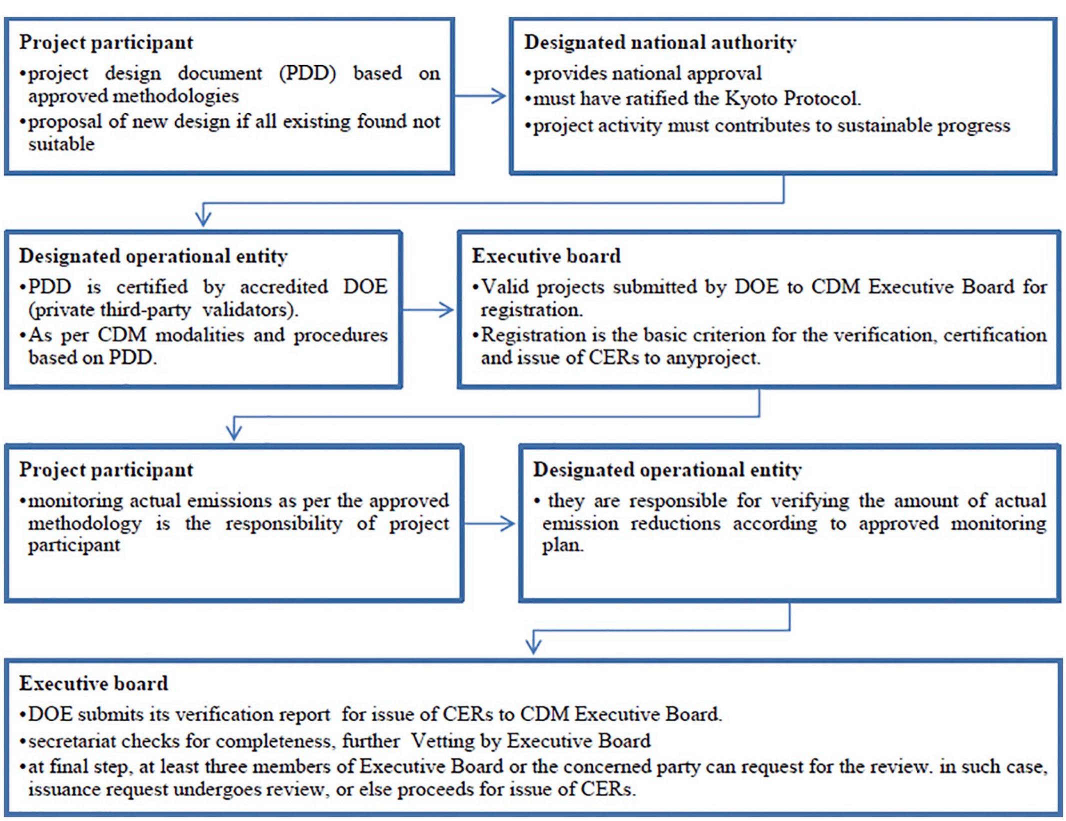

Fig. 4. Flow chart of CDM project cycle.

UNFCCC approved recommendations for REDD+ and called for nations to initiate actions for conservation and augmentation of sinks and reservoirs of greenhouse gases. REDD+ promises of comparatively larger and continuing financial support from multiple sources like the REDD+ Partnership, the Governors' Climate, and Forest Taskforce, the Green Climate Fund, and Voluntary Carbon Markets (Sills et al., 2017). REDD+ is expected to produce better results than the previous schemes to preserve forests (Venter and Koh, 2012).

REDD+ and other VCM mechanisms are in infancy and are expected to evolve further including new methodologies and dimensions. Since Bamboo grows on a variety of soils and can easily be incorporated into many productive systems. Bamboo's usefulness magnifies its options outside the boundary of forestry into agro-silvicultural and agricultural activities. INBAR is working towards inclusion of bamboo in all future climate change mitigation schemes (YannickKuehl et al., 2011).

5. Potential applications of bamboo

In India, bamboo is an integral part of life and finds usage in multiple ways. The domain of Bamboo application has been widening like never before with the development of bamboo processing techniques and a growing emphasis on using environment-friendly products. Broad categorization of major bamboo applications are given as:

5.1. Harvested bamboo products (HBP)

The bamboo plantation management involves selective felling of bamboo culms every year. Therefore, the carbon sequestration capacity depends on the usage, lifetime and durability of the material or the products made from the harvested culms. Some of the applications where bamboo is used in abundance are tools for agriculture and fishing, handicrafts, musical gadgets, furniture, foot bridges, scaffolding poles, paper, textiles board and laminated flooring (Scurlock et al., 2000). Comparatively longer Bamboo fibers (1.5 mm to 3.2 mm) are ideal for paper production (Bassam El, 1998). In India, two-thirds of total pulp production for the paper industry comes from bamboo. *D. strictus* is the most common and widely distributed species throughout the country. The Indian paper industry is dependent on this species to a considerable extent for raw material (National Bamboo Mission, 2015). The bamboo system behaves like a carbon sink, as long as the total volume of bamboo products keeps increasing. Lifespans of decades can easily be achieved with the new developments in processing and expansion of the product varieties. Increasing the carbon storage time increases the size of the bamboo carbon reservoir (YannickKuehl et al., 2011). Harvested Bamboo Products (HBP) are eligible for carbon credits generation under VCM only since comparatively more complex monitoring is required to ascertain carbon credits for other schemes. Any methodologies developed must avoid the double accounting of Emission Reductions. Variety of bamboo products like construction materials and pulp prolong the sequestration of carbon in HBP (Yiping et al., 2010; Kamesh and Lokesh Chandra, 2009).

5.2. Biochar from bamboo

Production of biochar from bamboo culms and bamboo products at their end of life is a great option of carbon sequestration and improving the agricultural produce of farms. Pyrolysis can convert up to 50% of the carbon from plant tissue to biochar. The remaining 50% carbon can be converted into energy. Due to its high surface area, biochar has the ability to retain nutrients for a long time. It helps in increasing water availability for plants with potential benefits to microorganisms (Yiping et al., 2010). Biochar has the retention time on soil up to thousands of years. Hence, it can be a prospective substitute to HBP as a long-lasting carbon reservoir. In addition to holding carbon, biochar also adds much-needed macro and micro nutrients (P, K, N, Ca, Mg, Cu, Zn, Fe, Mn) to the soil (Mankasingh et al., 2009). Biochar helps in reducing emissions of nitrous oxide (N_2O), a greenhouse gas from the soil (Oo et al., 2018). The worldwide application of biochar can negate upto 12% of present CO_2 equivalent emissions (Scurlock et al., 2000). Many organizations are working for the inclusion of biochar as Climate Change Mitigation (CCM) technology. The issue has been discussed on the many forums of UNFCCC (Yiping et al., 2010). However, the potential inclusion of biochar as a CCM technology within the UNFCCC remains uncertain.

5.3. Bamboo as a food source

Food shortage is also one of the byproducts of climate change. Bamboo can prove to be helpful in addressing food security in both human and livestock diets. The shoots of many species (such as *Bambusa balcooa*) are fit for human consumption, protein-rich and nutritious and are a common ingredient in many dishes. Additionally, bamboo leaves are used as fodder for livestock and fish (YannickKuehl et al., 2011). In North-East India, young shoots of some species are harvested between June and September annually and local population uses these shoots for consumption (Nath et al., 2018; Bhatt et al., 2003). The bamboo also has medicinal values. It is used in Ayurveda drugs to treat cough and asthma. Its burnt root is used as a medicine in the treatment of ringworm, bleeding gums, painful joints and wounds (Behari, 2006). In India, the leaves of Bambusa bamboos are used in the ayurvedic medicines for blood purification, leucoderma, and management of inflammatory conditions, bronchitis, gonorrhea and fever (Jansen et al., 1995).

5.4. Furniture and construction material

Bamboo is a locally available low-cost furniture raw material in most parts of India. It is strong and makes durable, elegant, lightweight and eco-friendly furniture (INBAR, 2017). In light of the country's flagship ‘Skill India’ programme, bamboo provides enormous opportunities for artisans and entrepreneurs to start their own enterprises with low investment.

Bamboo is a popular construction material in the regions where the plant has good natural growth such as South America, Africa and particularly South-East-Asia. Bamboo is suitable building material for earthquake-prone areas due to its high elasticity. The performance survey conducted after many earthquakes concluded that wood-frame construction could withstand the impact of large earthquakes without serious damage (Rainer, 1999). The added advantage of using bamboo is its fire resistance property due to the high content of silicate acid (GuaduaBamboo, 2002). Bamboo is a great ingredient for the environment-friendly interior from the aesthetics point of view. The usage of harmful paints can be avoided due to the naturally shining skin of Bamboo.

5.5. Energy from biomass

Large availability of bamboo can be used to produce Bio-energy, which is considered to be GHG neutral. No net contribution of CO_2 is made to the atmosphere from bio-energy (Fielden, 1999). Bamboo can be used to produce producer gas through gasification that can be used to produce electricity. The use of bamboo to replace dirty fossil fuel is eligible to generate carbon credits under both CDM and VCM (Kamesh and Lokesh Chandra, 2009).

6. Estimation of financial gains to farmers

Before exploring the potential economic impacts of bamboo, it is important to mention that the possibility of bamboo farming in already fertile land where traditional food crops are grown has been excluded in this study. Therefore, possible adverse impact on food production of the country is avoided. India has approximately 146 million hectares of

degraded land. Bamboo can be grown in this land with minimum resources (Bhattacharyya et al., 2015). According to NITI Aayog (top Govt. of India body on policy-making) report, during 2015–16 number of cultivators in India was 136 million with an average annual income of approximately 1750 USD at current exchange rates of 1 USD being equivalent to 70 Rs. (NITI policy paper, 2017). If available degraded land is evenly divided among all the cultivators, each will get 1 ha on an average.

The bamboos grown by families in Indian villages normally belong to Bambusa species (Nath et al., 2018). Most of the species belonging to Bambusa genus are tall and thick. (Banik, 2000). Per hectare, aboveground biomass storage from three most popular Bambusa species; B. cacharensis, *B. vulgaris* and *B. balcooa* is 34.88 ton, 81.74 ton and 41.79 ton respectively (Nath et al., 2018). If 20% selective felling per annum is assumed, the annual yield from three species will be 3.5, 8.2 and 4.2 t per hectare, respectively. Market survey reveals that currently, retail prices of bamboo in India vary between 80 and 100 USD per tonne. Hence, it can be concluded that farmers can earn 300 to 800 USD per hectare annually by selling raw bamboo from their degraded land. Since bamboo cultivation also improves land fertility, later on, the land could be used for other cash crops too (Yiping et al., 2010). As per census 2011, 54.6% of the Indian population is dependent on agriculture and allied activities. However, it contributes only 17.4% to the country's GDP (Annual report on agriculture, 2018). It means people working in the agriculture sector are under employed and some of them can certainly be utilized as skilled workers in bamboo-based industries. At present daily wage for skilled workers in India vary between 8 and 10 USD. Each worker can earn 2160–2700 USD annually by considering 270 working days per annum. This is significantly higher than the average farmer income of 1750 USD/year. Taking this skilled work force out of agriculture will reduce the total number of farmers solely dependent on agriculture. Hence, the average income of the remaining farmers will also improve. Profit from the sale of prepared handicraft will be additional to the entrepreneurs. 10 CERs per hectare can be generated from bamboo plantation annually under CDM and VCM schemes. It can be sold as carbon credits (Kamesh and Lokesh Chandra, 2009).

India's North-East Region (NER) is quite developed in bamboo handicraft industry. The products are beautiful and constitute a significant part of the handicraft export worth 215 million USD/year (Mandar et al., 2016). In NER Handloom and handicraft is the second most important economic activity after agriculture. NER contributes 19.18% of the total number of handicrafts units in India, 21.71% in terms of artisans and 79.58% in terms of the value of production. Every 14th person in the NE is dependent on handloom and handicraft products for livelihood. Handicraft sector provides more than 90% of livelihood to around 61% of the total artisan households in the region (DCH, 2010). Every state in NE India has some unique product. NE model may successfully be emulated by the rest of the country to generate new employment avenues.

With the preceding arguments, it is opined that the financial gains from direct selling of bamboo culms, CERs and employment generation in the bamboo handicraft field will boost farmers' income. If implemented properly, bamboo cultivation can contribute significantly to improving farmers' income by 2022.

7. Conclusion

The need for climate change mitigation has attracted international attention to the environmental benefits of bamboo. With its multiple applications, bamboo helps human kind both environmentally and economically. Hence, bamboo is also known as green gold. However, there are certain challenges in the process of fully harnessing the benefits of bamboo.

The potential benefits of bamboo and challenges on the path are summarized as follows:

(a) The carbon sequestration capacity of many species of bamboo is more than other high yield plantations. New methodologies are required to be developed for bamboo to get the advantage of emission trade mechanisms. Falling prices of carbon credits in the international market is also a concern. However, it is expected that these prices will recover after 2020, once the Paris agreement comes to effect.

(b) Promotion of bamboo can reduce dependency on fodder and small timber from the forest areas, thus helping in reduced deforestation. To reduce pressure on natural forests, farmers on their field bunds, backyards, village and farmlands, community lands and wastelands must adopt bamboo plantations on a large scale. It can be a good component of agroforestry system, which can supplement the farmers' income also.

(c) The bamboo industry is a labor-intensive industry and has the potential to generate millions of job. Bamboo provides fresh opportunities to entrepreneurs due to the unlimited possibilities of new applications of bamboo.

(d) Bamboo products made from untreated bamboo culms have a smaller life, which can be increased significantly by using some treatment methods. It also increases the commercial value of the products. More research and industrial investment are required to develop new products and improve the quality and life of existing products like bamboo laminates and bamboo tiles.

(e) Harvested Bamboo Products (HBP) and Biochar increase the sequestration period of carbon. Usage of HBP will also reduce our dependency on forests for wood and will reduce the deforestation. Biochar helps in improving the productivity of farms and reduces the requirements of fertilizers and water.

(f) In many areas of India, bamboo is an integral part of human life since ancient times due to its multiple uses, fast growth, easy cultivation, soil holding qualities and short rotation time. The low average productivity of bamboo in India compared to other countries like China and Japan is a concern. National Bamboo Mission (NBM) through its many projects is in the process to achieve higher productivity.

(g) Gregarious flowering of Bamboo is a major concern as it not only ends the life of bamboo forest but also damages other crops due to the appearance of excessive rodents after the mass flowering. Better infrastructure needs to be developed to handle such a situation.

(h) When compared to other plant-based options, the biggest advantage of bamboo is that all the necessities of farmers, fuel, food, and timber are supplied from the same piece of land. Due to its versatility and nutrients holding capacity, bamboo is one of the most suitable plants for the restoration of degraded land. The bamboo plantation is able to maintain a thick layer of litter. This litter layer helps in maintaining the microclimate and soil moisture on the surface and plays an important role in the eco-restoration of degraded lands.

Though unlimited opportunities exist with bamboo, there are certain challenges that can not be addressed by farmers alone. Concerted efforts by policymakers, agricultural research institutes and non profit organizations are required to achieve the true potential of this magical plant. The government of India by making the requisite change in legislation has given the much-needed shot in the arm that will go a long way in the promotion of bamboo cultivation in India.

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